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Problems in Sampling the Orientation of Fossils in a Graptolite Band at Eaglehawk, Victoria

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Abstract

Orientation studies of horizontal didymograptids, pendent tetragraptids, and of phyllocarid carapaces from four successive bedding planes in a shale bed from the railway cutting at Eaglehawk reveal random distributions as well as highly significantly directed ones. Directed orientations give way to random distributions from base to top of the bed for the three types of fossils studied.

Most significantly orientated were the didymograptids and the phyllocarids. Only those pendent tetragraptids with narrow stipe divergence were orientated significantly, suggesting that they were more sensitive to the current. The phyllocarids and pendent tetragraptids indicate a SE. or SSE. source, whilst the horizontal didymograptids were more meridionally aligned towards the top of the bed.

The question of sampling by several forms from one bedding plane, or by one form from several bedding planes to gain an estimate of the current direction at the locality, is discussed. The value of selecting the more elongate, or longest forms to obtain the most significant orientation pattern for all forms is demonstrated.

Introduction

The parallelism of graptolite rhabdosomes has been noticed on several previous visits to fossil localities of the Bendigo district. The Eaglehawk railway cutting terminating Parsonage Grove, south of the Bendigo tramline provides such a locality, where fossils are abundant. The six-inch shale bed is overlain by arenites which exhibit small-scale current bedding from a SE. source. Washout structures in sandstone filled with granule arenite occur in the creek drain, east of the new swimming-pool and lake reserve at Eaglehawk, also suggesting a southeasterly source for the emplacement of the arenites.

The purpose of this study was to determine whether or not the parallelism of the rhabdosomes was consistent with these directional structures; whether the same direction could be inferred from more than one bedding plane, from a combination of bedding planes, and from more than one form.

Method

An orientated slab, with the strike (N10°W) and dip (75°E) direction and magnitudes, in addition to base and top clearly marked thereon, was removed from the outcrop. A sheet of clear plastic could then be placed over the bedding plane, so that reference and rhabdosome lengths and directions could be traced on it with marking inks. The plastic sheet was then removed from the slab, superposed and suitably orientated on graph paper, so that photostat copies of the combination could be obtained from a Rank-Xerox copier for reference. Length and direction measurements could then be made from the photostat.

Rosettes on a 15° or 20° semi-circular or circular distribution could be constructed for bedding planes from the base, lower-middle, upper-middle and top of the 6-inch shale band. Fossils were classified hydrodynamically into the following three categories:

(i) horizontal short and extensiform didymograptids;
(ii) pendent tetragraptids;
(iii) phyllocarid carapaces.

Chi-square tests of significance for each rosette were made for a random hypothesis. Significance at the various levels was read from a set of statistical tables as Krumbein and Pettijohn (1965, pp. 418-420).

Modes of directed distributions were calculated by an algorithm outlined by Whittaker and Robinson (1962, p. 270), or by Schwarzacher (1963). The first harmonic only was considered. Initially in Figs. 1 and 2, the sense of orientation of the rhabdosome was ignored for didymograptids and phyllocarids, so that the distributions were semicircular in that class intervals were in the range of 0 and 180°. Thus the distributions in these were symmetrical, whereas the pendent tetragraptids were scored in classes between 0 and 360°, since their asymmetry dictated a proximal and distal end to the rhabdosome as regards the current sense. Even so, in spite of the asymmetry of the distribution, it is possible to detect in the rosettes of the pendent forms an approximate axis of symmetry which corresponds to the current direction.

Previous Work

R. Ruedemann (1897) noted the parallel orientation of graptolite rhabdosomes, sponge spicules, bryozoan fragments, and straight cephalopods in the Utica Shale. The apices of the cephalopods and the siculae of the graptolites pointed eastwards, from which was inferred an ENE. current.

H. Hundt (1938) ascribed parallel graptolites to the effects of bottom currents. D. Krinsley (1960) presented a rosette for the orientation of 106 orthoceracone cephalopods on a single bed at Lemont, Illinois. As the primary or *a*-mode was from 290°, and the secondary or *b*-mode was normal to it, a WNW. source was inferred. A *b*-mode transverse to the current direction is to be expected if the lengths of the orthoceracones varied, or if the current varied in intensity and direction during deposition, or if reworking occurred after deposition. The shorter particles can be fickle to turbulence while the longer forms are less likely to be turned from their orientation, in virtue of their inertia.

Skwarko (1962) ascribed the orientation of diplograptids at Cobb River in New Zealand to tectonic deformation. W. Schwarzacher (1963) presented rosettes of crinoid stems from many localities to deduce a current pattern in the Carboniferous limestone of the Benbulbin area, Sligo County, Ireland. He demonstrated that a unidirectional current could produce a polymodal rosette, depending on the prevailing current conditions at the time. When there were more harmonics present, more sub-maxima developed.

Ager (1963) demonstrated the behaviour of the orientation of belemnite guards in relation to size. Guards less than an inch long pointed in the opposite sense to those longer.

Theory of Orientation Modes

Orientation modes, whether circular or semi-circular, usually present two directions of symmetry or approximate symmetry, which may be perpendicular to each other. One is the current direction, the other is transverse to it. The problem is to identify the dominant or *a*-mode of the rosette with the current direction or with the normal to it.

By experiment, Schwarzacher (1963, p. 584), was able to demonstrate with crinoid stems that where the current was fast, the *a*-direction bisected the acute angle between the two prominent complementary modes. Where the current was slow, the current direction bisected the obtuse angles between the modes.

The liquid impact I on a particle is the product of the square of the speed of the current, v, and the area A_n of the particle which is normal to the current. Thus, for an elliptical plate (which might simulate a phyllocarid carapace) of semi-major and semi-minor diameters a, b respectively, aligned at angle θ to the direction of the current of velocity v,

$$I = kv^2 A_n \tag{1}$$

where k is a constant depending on the environment.

$$\text{Thus, } I = kv^2 \pi ab \, . \sin\theta$$

$$\text{or} \qquad \sin\theta = \frac{I}{\pi\, kv^2\, ab} \tag{2}$$

If I is to remain constant, and v is a maximum, then $\sin\theta$ will tend to be small. This means that the elliptical plate tends to align itself with its long axis parallel to the current. With decrease of speed, $\sin\theta$ tends to enlarge, so that the plate tends to lie transverse with the current, with an accompanying increase in randomness of the modes.

Results

1. Nature of the Population

The composition of fossil forms from the four bedding planes sampled at Eaglehawk is given in Table 1.

The most abundant forms are *Tetragraptus fruticosus* (3-branched form), horizontal didymograptids, and oval phyllocarid carapaces. These thus formed the basis of the orientation study, but sufficient forms of *Tetragraptus pendens, Didymograptus dilatans*, and *D. similis* were available for outcrop study by cumulating all four samples. A minimum of 12 samples was required for a 15° class, semi-circular distribution, or for a 30°, circular distribution.

2. Sampling By Bedding Planes

Bedding plane 1, the basal representative, is shown in Fig. 1A, B. Fig. 1A shows the 15°, semi-circular distribution for horizontal didymograptids. The orientation of the stipes is plotted against the frequency for the midpoint of each 15° of arc. No provision was made for the position of the sicula or thecae on each rhabdosome. Thus the 15° midpoint shows two stipes aligned between N.7½°E. and N.22½°E. but whose thecae could be facing either NW. or SE. The current direction for the rosette is inferred as the bisector of the acute angle between the primary modes rather than the obtuse angle bisector, in the light of the distribution of Fig. 1B, and the SE. current bedding in the arenites overlying this shale band.

Fig. 1B is a 20°, circular distribution for the combination of *Tetragraptus fruticosus* (3 Br.) and *T. pendens* specimens. The rosette clearly shows a SSE. source, with most of the proximal portions of the of the rhabdosomes being directed up-current. Unit circles for figures of rosettes are unlabelled, and unless otherwise specified, indicate one observation per unit increase in radius.

Fig. 3 is a line graph plotting the significant difference from random orientation as determined by chi squared for 11 degrees of freedom, for the three distributions for each bedding plane as portrayed in Figs. 1 and 2.

TABLE I

Analysis of Fossil Forms from the Four Bedding Planes scored for Orientation Studies, Railway Cutting, Parsonage Grove, Eaglehawk

Fossil Forms	Frequency:	No. per 100	
PENDANT TETRAGRAPTIDS:			47
	T. fruticosus (3 Br.)	35	
	T. pendens.	9	
	T. pendent sp. indet.	3	
OTHER TETRAGRAPTIDS:			4
	T. serra	4	
HORIZONTAL DIDYMOGRAPTIDS: (inc. *D. abnormis, D. ensjoensis, D. similis*)			25
OTHER DIDYMOGRAPTIDS:			8
	D. dilatans	5	
	D. hemicyclus	3	
OTHER ANISOGRAPTIDS:			4
	Phyllograptus sp.	1	
	Multiramous forms (esp. *Goniograptus macer*)	3	
PHYLLOCARID CARAPACES			12

In the case of the 18-class, 20° sector for tetragraptids, conversion was made to 11 degrees of freedom from the formula:

$$\chi^2_{11} = \frac{11\,\chi^2_{17}}{17} \tag{3}$$

This has allowed some comparison of relative significance of all three orientation patterns on the one diagram. The line graphs of Fig. 3A show that all the tetragraptid distributions were random, all the phyllocarid distributions were directed, and that the lower middle and upper didymograptid distributions were random. The lower set of line graphs shows most divergence of directional modes in the middle of the bed, and closer agreement between tetragraptids and phyllocarid directions, the mean direction of all forms being southerly.

DISCUSSION

Fig. 1C, D, E shows the orientation patterns from the lower middle bedding plane. Both didymograptids and tetragraptids fall below the level required for significant directed orientation, but rosettes suggest a southerly current source. Phyllocarids are more strongly directed with a SSE. mode. The configuration of of the modes suggests a decline in current strength for the didymograptids and tetragraptids, which is confirmed by the random orientation of the rosettes as a whole. The tetragraptids in this sample were shorter in length when compared with those of Fig. 1B. Equation (2) suggested that shorter rhabdosomes would lie more transverse with the current, since sin θ is inversely proportional to a, the long dimension. Thus Fig. 1D tends to approach the butterfly-like b-pattern of Schwarzacher (1963, p. 581, Fig. 1; p. 584, Fig. 4B), but with the proximal portions tending to point up-current. The difference in direction of the rosettes of didymograptids and tetragraptids from the phyllocarids could be explained in

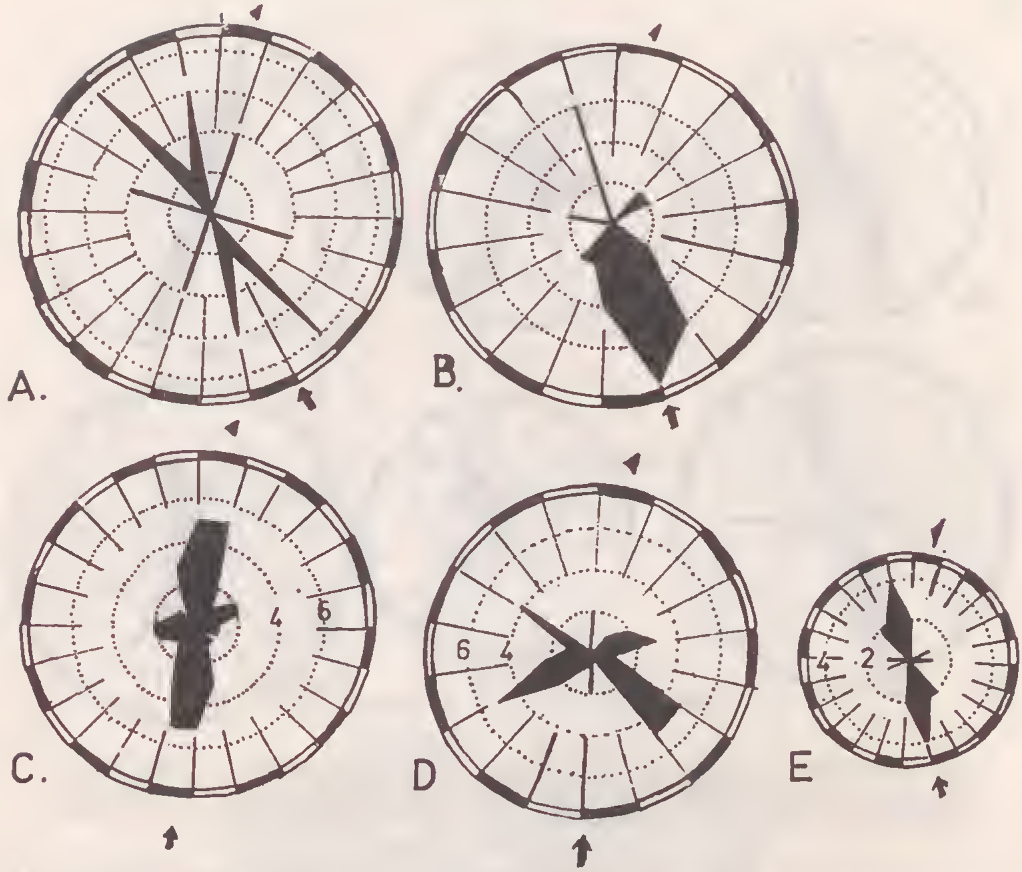

Fig. 1—Orientation distributions of fossils from the basal pair of bedding planes at Eaglehawk. A, B—Basal Plane 1; C, D, E—Lower Middle Plane 2; A, C—Horizontal didymograptid rhabdosomes (15° semi-circular distributions); B, D—Pendent tetragraptids (20° circular distributions); E—Phyllocarid carapaces (15° semi-circular distribution).

terms of the former two groups being pelagic, and settling in more gravitationally directed trajectories through the water, whilst the phyllocarids could have been brought in by a stronger SSE. current operating close to the ocean bed.

Fig. 2A, B, C shows the three corresponding distributions for the upper middle bedding plane. Pendent tetragraptids are even more random, but rosettes for didymograptids and phyllocarids are highly significantly directed, from SSW. and SSE. respectively. If any directional mode can be attached to Fig. 2B it would be from the SSE., but there is also a SSW. secondary mode. It is suggested that the pelagic tetragraptids were realigned by later currents which brought in didymograptids from the SSW. and SSE. in separate phases. The bedding plane records fossil forms which suggest multidepositional events during which there could have been winnowing and realigning of already deposited forms.

Fig. 2D, E, F shows a decline in significant directional properties with respect to the upper middle bedding plane. The return of the phyllocarids and didymo-

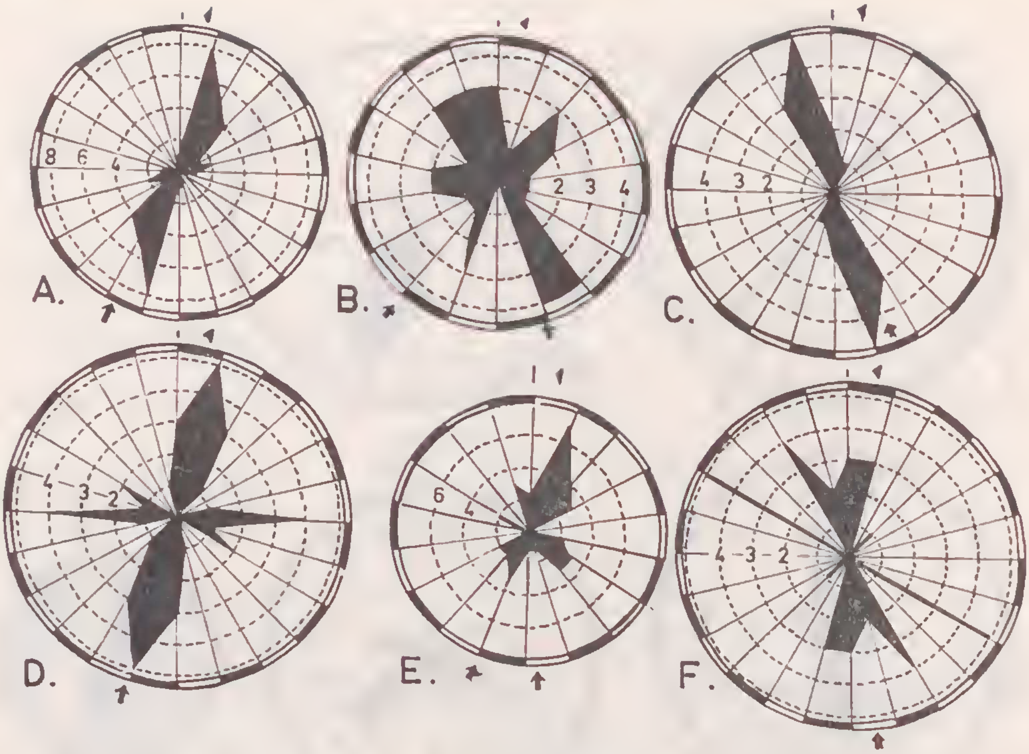

Fig. 2—Inferred directions for the orientation distributions from the upper pair of bedding planes at Eaglehawk. A, B, C—Upper Middle Plane 3; D, E, F—Uppermost Plane 4; A, D—Horizontal didymograptids; B. E—Pendent tetragraptids; C, F—Phyllocarids.

graptids to random orientation to different degrees suggests weaker eurrents and a return to a more southerly souree. If the relative strengths of the two different currents reeorded in Fig. 2A-C are refleeted in Fig. 2E, then the SSW. current could have been responsible for the alignment of the tetragraptids in the NNE. mode, and perhaps the transverse mode in the phylloearid rosette. Both of these modes could have been the product of realignment of tetragraptids and phylloearids when the SSE. current persisted into the later stages of deposition of the 6″ shale band.

Suggestions For Further Study

1. The sampling by bedding planes deseribed above has suggested impressions of the multi-depositional nature of the sediments deposited in the environment of the Bendigo Goldfield.

2. The base of the bed was deposited by a uni-direetional current from the SSE., of different speed strengths as evideneed by aeutely separated direetional modes, and significantly direeted rosettes.

3. With further depositional phases, SSE. and SSW. sourees were suggested by the didymograptid and phylloearid populations, when their direetional properties were studied separately.

4. Consideration of the random orientation of the pendent tetragraptid popula-

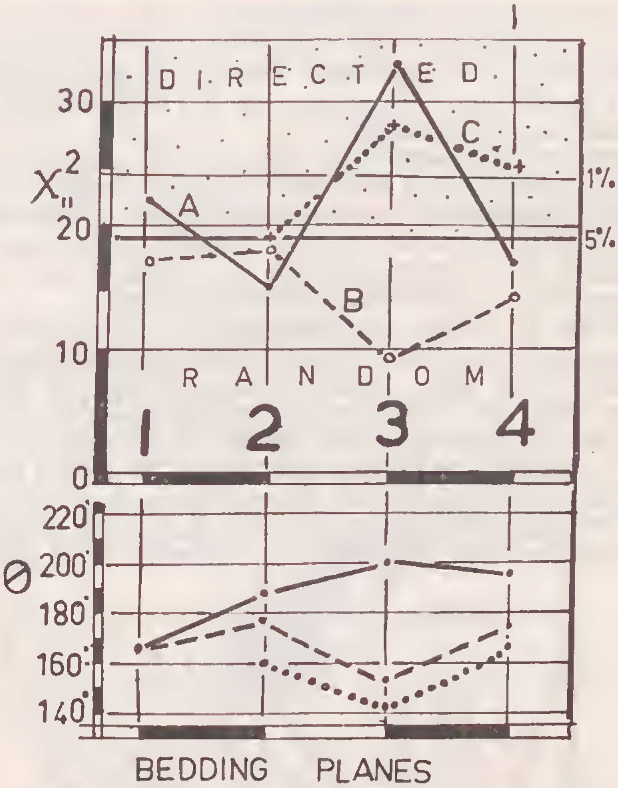

Fig. 3—Line graphs showing the stratigraphical variation of the significance and direction of orientation of the three fossil forms. A—Firm line (horizontal didymograptids); B—Broken line (pendent tetragraptids); C—Dotted line (phyllocarids).

tion throughout suggests that these may have been pelagic and some of these were winnowed and realigned when the SSE. or SSW. currents brought in the didymograptid and phyllocarid forms.

5. Closing phases of deposition suggested weakest currents with persistence of the SSW. bias, as suggested by more random modes, and symmetry considerations of the rosettes as a whole.

3. Sampling from the Whole Outcrop by Studying the Orientation of Individual Forms

(a) *Tetragraptus fruticosus*: (3 Br. form). Pendent tetragraptids are suitable rhabdosomes for demonstrating the effect of distortion. If later compressive movement of the sediments is a factor in orientation, the stipe spread would be expected to be least perpendicular to the stress axis, and greatest in the direction of maximum compression. A study of stipe divergence was made in relation to length and orientation to gain some measure of the effect of stress deformation in particular directions.

Stipe divergence was measured by the ratio l/w, where l is the length of the rhabdosome from the first bifurcation to the distal end, and w is the distance across the distal extremities of the stipes perpendicular to the line of l, as indicated in Fig. 4. It should be realized that stipe divergence could be a function of the stage of growth of the species, since older forms become deflexed, the ratio l/w decreasing suddenly at a given length. As specimens in this band were less than one inch, this gerontic feature was not present.

Fig. 4 demonstrates the change in the ratio l/w with increase in the length of a typical *Tetragraptus fruticosus* (3 Br.), in forms whose lengths do not exceed one inch. In all cases, as the rhabdosome grows, it elongates to a critical limit. Beyond this limit *T. fruticosus* stipes tend to curve outwards, so the ratio l/w decreases sharply in gerontism. If a current hypothesis is entertained, one would expect the more elongate particles to be the better indicators of current.

Fig. 5 shows the distribution of orientations of *T. fruticosus* (3 Br.) in relation to stipe divergence ratio (l/w). Table 2 summarizes the main features shown by the compound rosette. Since the more elongate forms are transversely distributed, as well as along the *a*-direction, the current hypothesis is favoured rather than orientation due to secondary stress factors. In some instances thecae may be distorted, but not complete rhabdosomes as figured by Hills (1965, p. 123, Fig. V-19). The smaller widespread forms are variable, and show the best symmetry in a NE.-SW. direction. This direction could be interpreted as tranverse to a SE.-SSE. current source, or to the response of realignment with a strong SSW. current

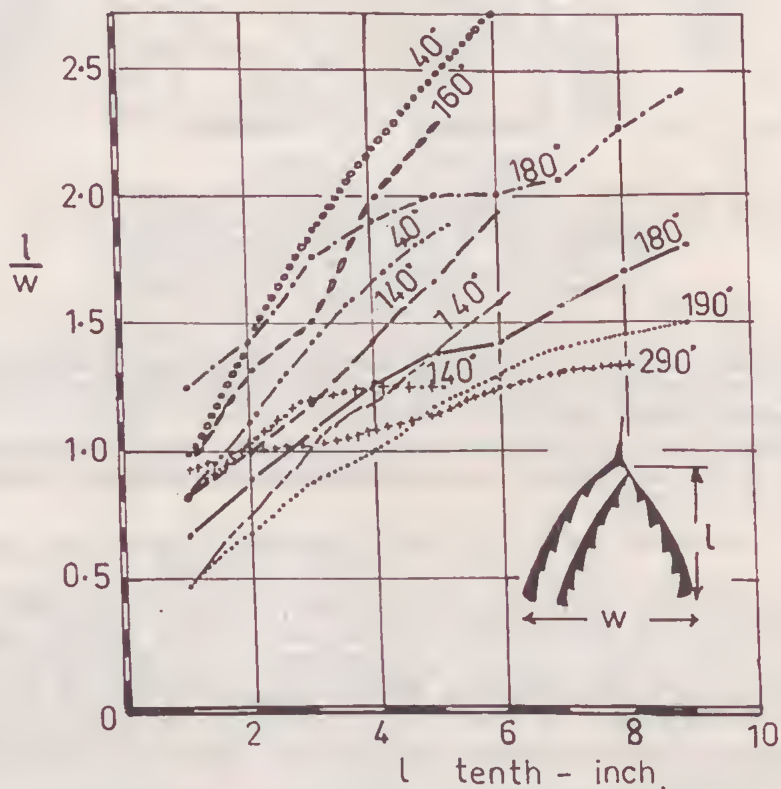

Fig. 4—Growth variation of stipe divergence of 10 of the longest *Tetragraptus fruticosus* (3 Br.) forms and their orientations.

which aligned the majority of horizontal extensiform didymograptids. In any case, the short, widely-diverging forms were fickle, and not accurate current indicators. The larger, elongate forms proved to be the more reliable indicators of current direction, which was from S.40°E.

(b) *Horizontal Didymograptids:* Size-orientation studies were carried out for the whole outcrop sample on horizontal extensiform didymograptids with fragmentary stipes and with complete rhabdosomes. Circular 30° class distributions allowed the determination of the significance of the attitude of thecae in relation

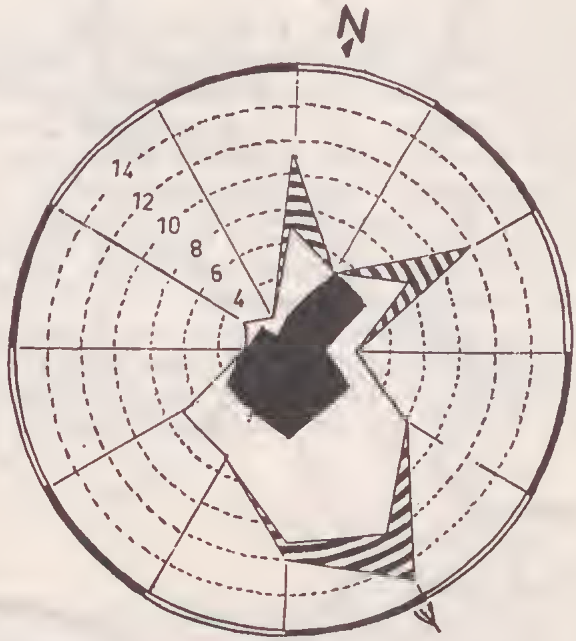

FIG. 5—Orientation of three classes of *T. fruticosus* (3 Br.) based on stipe divergence. Sample collected for the whole outcrop. (a) Striped: l/w = 2·0+; (b) Blank: l/w 1·5 to 2·0; (c) Black: l/w less than 1·5.

TABLE II

Analysis of Orientation of Tetragraptus Fruticosus (3 Br.) in terms of the Stipe Divergence Ratio (l/w) for all samples

Stipe Divergence Ratio (l/w)	Less than 1·5	1·5-2·0	Greater than 2·0
No. in Sample	42	36	12
Chi. Square Value (11 d.f. random)	6·0	22·0	30·0
Probability of random orientation	80%-90%	1 to 2·5%	0·5% to 1%
Inferred current source direction	140° and realignment from 210°	140°	140°

to stipe orientation. The direction of the sicula, (taken to be perpendicular to the stipe direction, but opposite in sense to the direction the thecae face), is plotted in relation to frequency in Fig. 6. Fig. 6A shows a transverse pattern for sicular orientation, with a small secondary mode pointing up-current, which gives the *a*-direction. This pattern is confirmed in Fig. 6B for the fragmentary stipes. There is no significant difference in the length of stipe studied. It was difficult to find sufficient numbers of short, horizontal rhabdosomes to compare with the tetragraptids less than 0·5″ (1 cm). The didymograptids have been aligned in a SSW. to S. direction with a small percentage of thecae pointing directly up or sub-transversely down current.

(c) *Didymograptus similis*: Fig. 7C, D shows the SSW. pattern as evidenced by normally disposed primary and secondary modes. *D. similis* incorporates all species with narrow proximal stipes flaring distally, usually less than 1·5″.

(d) *Didymograptus dilatans*: Fig. 7A, B shows the semi-circular distribution of the direction of that line equally inclined to the two stipes, and parallel to the join of the distal extremities of the rhabdosome, and the orientation of the sicula direction, respectively. The proximal angle of *D. dilatans* points obliquely downcurrent. Long stipes tend to sub-parallel or equally align themselves to the current direction, which is SW., and which largely agrees with that indicated by the alignment of the extensiform didymograptids.

(e) *Tetragraptus pendens*: It was not possible to obtain significant rosettes for the whole outcrop of *T. pendens*, even when the largest l/w values were considered. However, when samples for the lower pair of bedding planes were considered in relation to the upper pair, two significant distributions emerged as shown

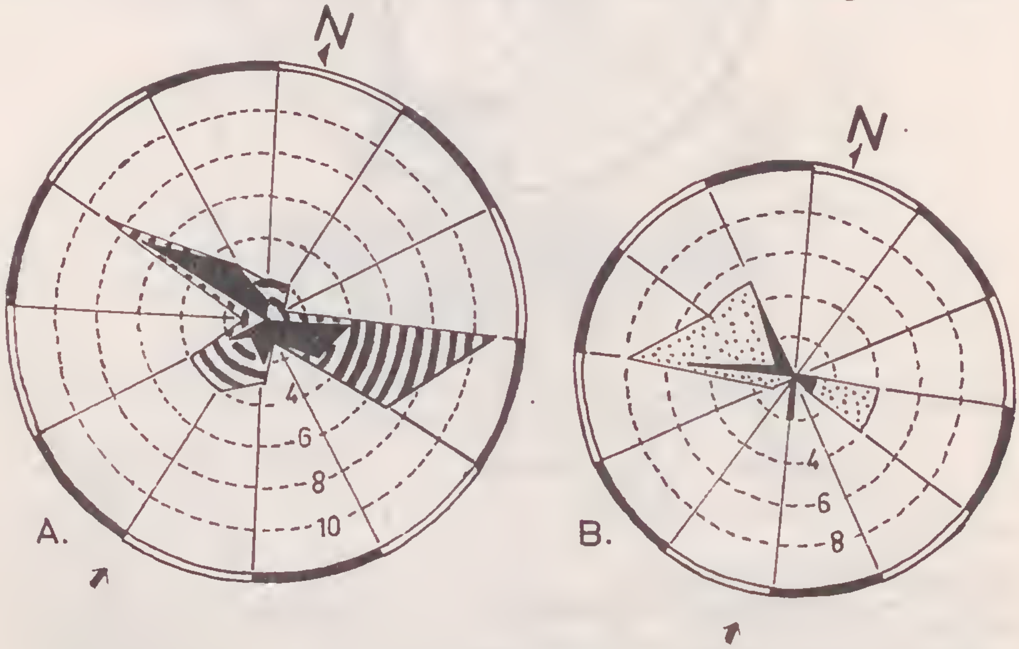

FIG. 6—Orientation directions of the siculae of horizontal extensiform didymograptids from the whole outcrop at Eaglehawk. A—Complete rhabdosomes: Black—less than 1″ long, Striped—more than 1″ long; B—Fragmentary rhabdosomes: Dotted—fragments longer than 1″, Black—not necessarily longer than 1″, but measured as definitely shorter.

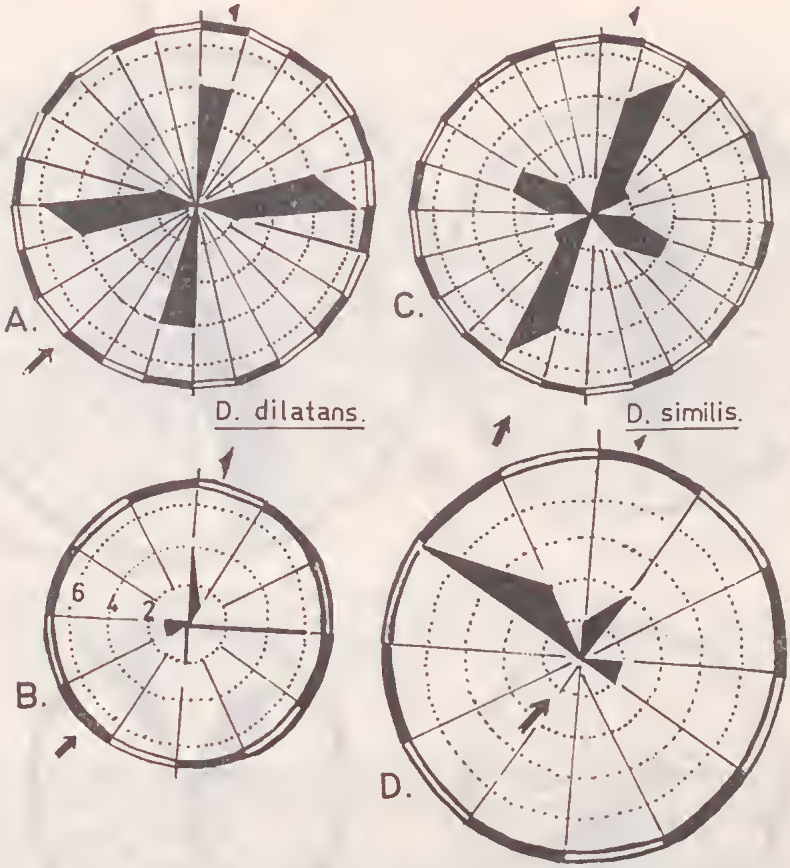

FIG. 7—Orientation patterns for *D. dilatans* (A, B) and *D. similis* (C, D). A, C—15° semi-circular distributions showing rhabdosome directions; B, D—30° circular distributions showing directions siculae were pointing.

in Fig. 8A, B. The lower bedding planes revealed a SW. current as with forms in Fig. 1A, B whilst the upper planes produced a symmetry which suggested a more southerly source. The interesting feature was that the siculae pointed dominantly downcurrent. At least the orientation patterns of *T. pendens* agree closely with those of *T. fruticosus* (3 Br.) and it would appear that both forms have been aligned in directions fitting a superposition of SSW. and SSE. directions. In general *T. pendens* is not a good indicator of current, but, when considered in conjunction with *T. fruticosus* (3 Br.) the sample of pendent tetragraptids becomes large enough to be significant.

(f) *Phyllocarid Carapaces*: Phyllocarids were studied for size and eccentricity of carapace in relation to the orientation direction. Fig. 9A portrays the orientation distribution in relation to the three categories of length. Carapaces less than 0·2″ were classified as short in length, 0·2″-0·4″ of medium length, and those above 0·4″ were regarded as long. The long ones were the most significantly orientated, the inferred direction being from the SSE.

The eccentricity *e* of the carapace is defined as the length-width ratio and Fig.

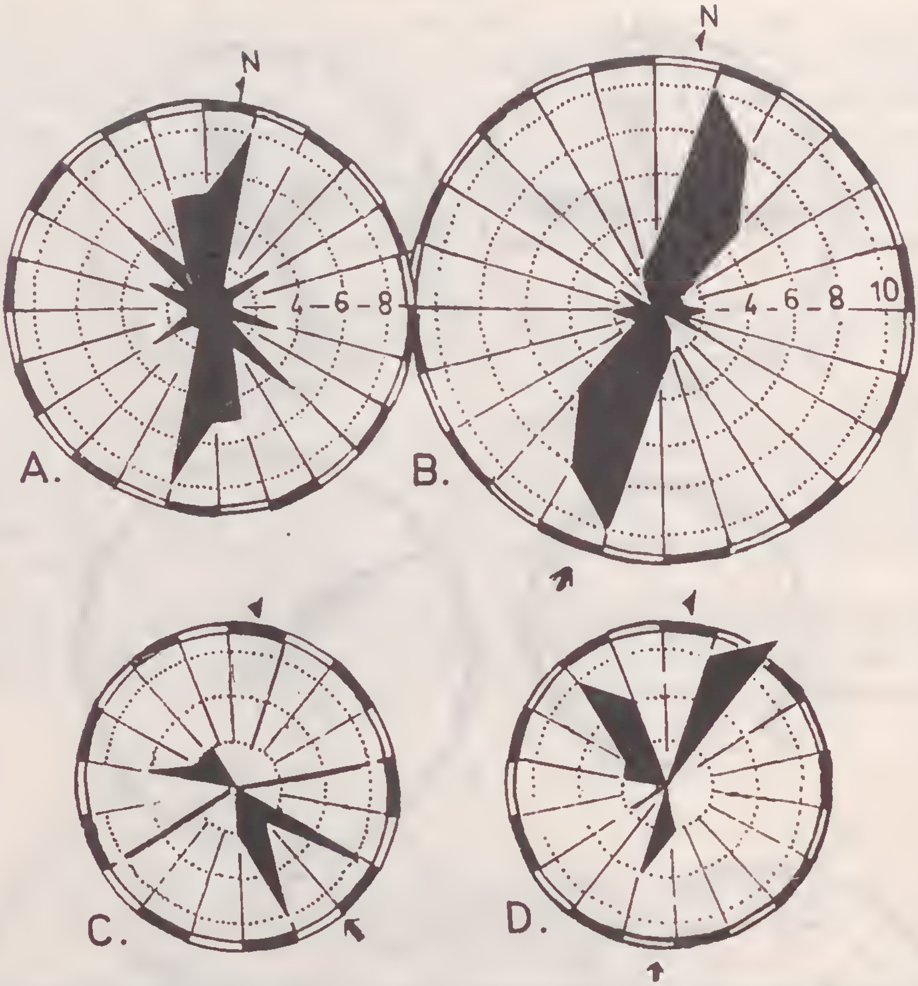

FIG. 8—Rosettes comparing orientations of horizontal didymograptids (A, B) with *T. pendens* (C, D) from lower and upper stratigraphical halves (AC, BD) respectively.

9B shows the relation between orientation and eccentricity. Again, the more elongate carapaces were most significantly orientated, again from the SSE. Carapaces below 2·6 *e* were not significantly orientated from random.

SUMMARY

At Eaglehawk, orientation studies dependent on form or species benefit greatly from size and shape sampling. The more reliable indicators are linearly shaped. In another study on the orientation of diplograptids from the Upper Ordovician localities of Toolern Vale and Diggers Rest, the author has shown that the longest forms prove to be the most reliable current indicators (Schleiger 1968). See Fig. 10.

Phyllocarids and pendent tetragraptids show a significant alignment consistent with a SSE. direction. Horizontal didymograptids on the other hand show a SSW. orientation pattern. The successive samplings in the rosettes suggest that the SSW.

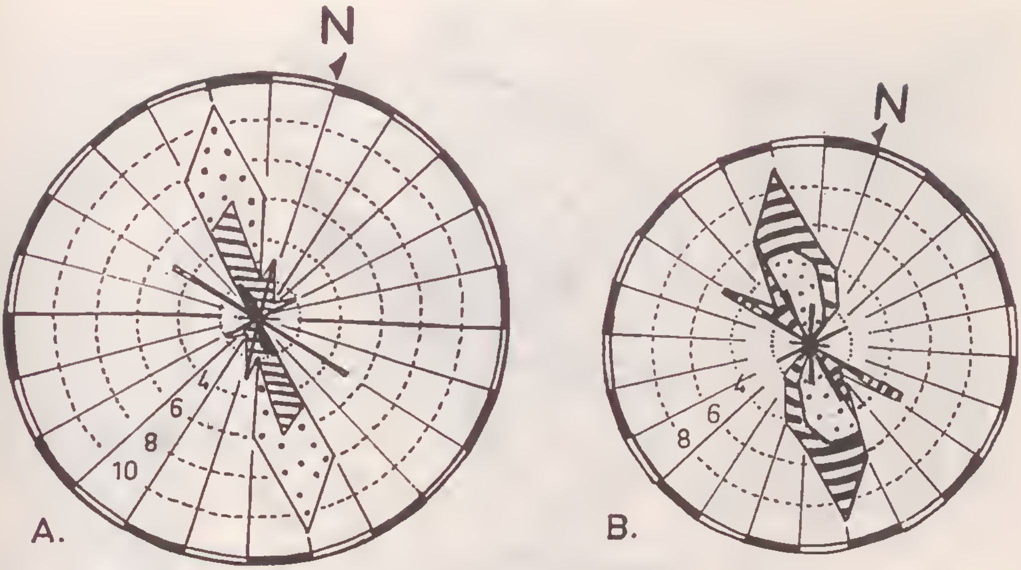

FIG. 9—Orientation of phyllocarids in relation to length and eccentricity of carapace. A—Length classes: Stippled—less than 0·4″ long, Striped—from 0·2″-0·4″, Black—less than 0·2″; B—Eccentricity classes: Striped—3·2+, Stippled—2·7 to 3·1, Black—less than 2·6.

current was operative in building up the later thicknesses of the bed, with the phyllocarids and tetragraptids showing some evidence of realignment in the uppermost bedding planes.

Otherwise a morphological hypothesis could suggest that the phyllocarids and pendent tetragraptids rotated or screwed as they settled through the current, since they were broader forms offering more resistance. Such rotatory motion could have produced modes at 40° to those of the linear extensiform didymograptids brought in from the SSW.

Whatever the reason, a vector mean of 168° can be calculated from the various rosettes (Tables III, V).

4. Methods of Sampling Graptolite Orientation

From the foregoing study the question of the best method of sampling of orientation patterns now suggests itself.

(a) Is a sample from one bedding plane using several forms representative of the whole outcrop?

(b) Is a study of one form over two or more bedding planes a better representation?

(c) Is a study of several forms collated from all bedding planes sampled, as good as either of the former two?

To test these three hypotheses, an analysis of variance was undertaken on the three estimates of the results, viz.,

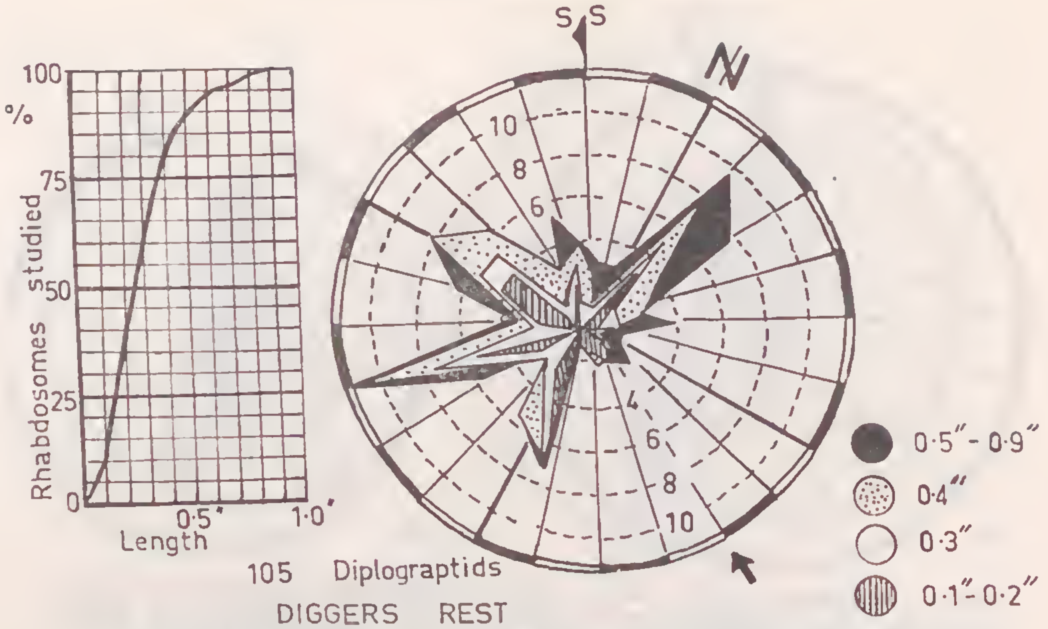

FIG. 10—Rosette showing the relation between length and orientation modes of diplograptids with inferred current. Individuals show a normal length distribution at left. Bolindian (Upper Ordovician). Locality on Jackson's Creek at 'Glencoe', Diggers Rest. ss: structural strike.

(a) those obtained from separate bedding plane samples; (3 forms and 4 planes);

(b) those obtained from rosettes of four forms from the lower and upper halves of the bed, by collating planes 1 and 2, contrasted with the combination of 3 and 4;

(c) those obtained by collating 12 different forms from the whole outcrop.

Table 3 presents the estimates for the three methods of sampling, and Table 4 the analysis of variance. It can be seen that of the various methods by bedding planes, by stratigraphical subdivision into two halves, and by collation for the whole outcrop of several forms, none is more accurate than another. However, species sampling does reveal significant differences at the 1 and 2·5 per cent levels. Thus, if the method of sampling involves only one species, it could lead to a result

TABLE III

Estimates for the Three Methods of Sampling of Graptolite Orientation Patterns, Eaglehawk

Sampling Method Species	A. Whole Outcrop	B. By Bedding Planes	C. By Lower & Upper Stratigraphic Halves
Horizontal Didymograptids	180, 185, 200, 185, 215, 190	140, 180, 205, 190	170, 195
Pendent Tetragraptids	210, 140, 140	150, 170, 165, 180	135, 180, 140, 145
Phyllocarid Carapaces	135, 140, 150	150, 155, 165	155, 160

TABLE IV

Analysis of Variation for the Three Methods of Sampling in Relation to Species of Table III

Source of Variation	Sum of Squares	D.F.	Mean Square	F
Total for cells	8542·0	8		
Sampling methods	753·4	2	376·7	1·97
Species	7025·5	2	3512·8	18·41*
Species X sampling methods	763·1	4	190·8	
Within cells	8695·0	22	395·2	
Species in relation to within cells				8·89**

* Significant at the 1% level
** Significant at the 0·5% level.

TABLE V

Analysis of Sampling by Bedding Planes in Relation to like Hydrodynamic Forms of Orientation Patterns

Hydrodynamic Form	Bedding Plane Sampled				Total	n	Mean
	Base	Lower Middle	Upper Middle	Top			
Horizontal didymograptids	140	180	205	190	715	4	178·3
Pendent tetragraptids	150	170	180	165	665	4	166·3
Phyllocarid carapaces	NA	155	150	165	470	3	156·7
Total	290	505	535	520	1850	11	168·2
n	2	3	3	3		11	
Mean	145·0	168·3	178·3	173·3			168·2

TABLE VI

Analysis of Variation for Table V

Variation	Sum of Squares	D.F.	Mean Square	F. Ratio
Total	3763·6	10	376·36	
Bedding Pls.	1463·6	3	1254·4	4·35 (Sig. 5-10%)
Species	859·4	2	429·7	1·49
Error	1440·6	5	288·1	

which may not be truly representative of the inferred current direction at the locality.

Table 4 presents the method of sampling by bedding planes, in relation to only the three most abundant species. The analysis of variance indicates that forms on one particular bedding plane do not yield significantly different results from one another, but that bedding plane samples alone are almost significantly different from each other (at the 5 to 10% level). This calls for caution in taking individual bedding plane samples as representative. It would suggest that it would be safer to include approximately equal samples from several bedding planes for the most representative result.

SUMMARY

Where many graptolite forms are present, current direction from orientation sampling is best inferred by collating the more abundant, most elongate forms over two or more bedding planes. The more forms used, the more accurate will be the inferred direction. Preliminary sampling, however, will indicate whether it is worth while dealing with more than two forms, especially if bedding plane sampling is kept progressive, and the numbers of individuals kept in lots of 12 or 18 for ease of computation.

Inferences

1. Significant orientation of the commonly occurring fossil forms demonstrates the influence of primary current action rather than the effects of directional stress. Justification for this is realized in the study of the stipe divergence ratio of *Tetragraptus fruticosus* (3 Br.) where the longer, narrower forms were aligned in more than one direction, as were the short ones.

2. Sampling by four bedding planes of a six-inch shale bed on the orientation of horizontal didymograptids, pendent tetragraptids, and phyllocarid carapaces, reveals that the strongest aligning currents operated at the base of the bed; first unidirectionally from the SE., changing to S., then from the SSW., persisting to the deposition of the top of the bed.

3. The shift to SSW. was accompanied by strong orientation of horizontal didymograptids, realigning the shorter pendent tetragraptids and some oval phyllocarids, which already showed SSE. to SE. modes.

4. The longer, or more elongate particles were the most reliable indicators of current direction.

5. Methods of sampling by forms from the whole outcrop, or by stratigraphic units, are considered. Stratigraphic collation methods at Eaglehawk were not significantly different from each other. However, it is unsound practice to rely on one form from one bedding plane as being representative of the inferred direction at the outcrop. Rather two or more species from at least two or more bedding planes should prove more representative.

6. Whether the turbidity currents responsible for the abundance of graptolites over the shale bedding planes (Hills and Thomas 1954) were also responsible for the orientation of these fossils is not proven. It is reasonable to argue that the aligning current was associated with the same series of slumping movements which produced the turbidites which proved toxic to the graptolites. The initial slumping probably involved the emplacement of the heavy arenite beneath the graptolitic shale at Eaglehawk. The graptolitic shale represented the cloudy tail of clay particles left in the turbulent wake of the slump. If the turbulence circulated into the upper levels of the sea, with a toxic effect on the graptolites, it would be expected

that after these gravitated to the bottom, currents raking the floor, either the tail of the same turbidite or later bottom currents, would realign the rhabdosomes and phyllocarids.

Acknowledgements

The author is grateful to Messrs Gil. Medwell, Henry Moors, and Neil McLaurin for assistance in the field. Dr and Mrs John Talent, and Henry Moors were particularly helpful in their comments during the composition of the manuscript. Dr F. C. Beavis, Dept. of Geology, University of Melbourne critically read the manuscript, and gave helpful advice and encouragement during the project. Mr John Inglis of Coburg Teachers College gave valuable assistance with the photography. Costs were partly defrayed by a grant from the Science and Industry Endowment Fund, administered by C.S.I.R.O., East Melbourne, and part of the cost of publication has been met by the University of Melbourne.

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Explanation of Plates

Plate 1

A: Portion of the basal bedding plane showing extensiform didymograptids aligned along current, whilst the shorter rhabdosomes lie transverse to the current, which is from the SE. as indicated by the arrow.

B: Enlarged section of the left illustration to show a typical relationship between long didymograptids and pendent tetragraptids. Current indicated by arrow.

Plate 2

Relation between aligned tetragraptids and transverse bedding parting lineation. The larger *T. fruticosus* (3 Br.) points proximally up-current (see arrow). The shorter form parallels the transverse bedding parting. Forms from Bedding Plane 1. (See Fig. 1B.)